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SOME PROBLEMS IN DESIGN AND CONSTRUCTION OF TEMPORARY RETAINING STRUCTURES

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SUMMARY

Even though the number of construction cases of temporary retaining structures in urban area are increasing, there still are many problems to be solved in design and construction of temporary retaining structures. In this paper the current design methods are reviewed and their problems are analyzed. Some critical mistakes made by site technicians and engineers are also discussed.

INTRODUCTION

In recent years, the strict regulations on parking space for bulding in urban area led to needs for more subsurface space for tall office buildings. Therefore the depth of excavation for new buildings have been increased. Nowadays more than 30 m deep excavation is not uncommom.

As the depth of excavation grows, the importance of integrity of temporary retaining structure is greatly emphasized. The retaining structure should not only be safe against failure but also consists of such structural systems that the excavation work imposes the minimum adverse effect on the adjacent ground and structures.

In this paper, the types of temporary retaining structures recently adopted in Korea are reviewed, and the problems and mistakes in design and construction of such structures are analyzed in the hope of improvement of our construction technologies.

TYPES OF TEMPORARY RETAINING STRUCTURES

Wall system

The following types of wall system for temporary retaining structures are currently in practice in Korea.

(1) Soldier pile and wood lagging

This is the most widely used wall type in Korea. Until about 10 years ago, most walls of retaining structures were of this type. Therefore contractors are well experienced, and sometimes overconfidenced.

But this type of wall is the worst with respect to causing damages to adjacent structures. In constructing this type of wall, natural ground is exposed without any support until wooden panel is inserted between soldier piles. This exposition of natural ground results in movement of ground behind the wall and groundwater inflow, which causes loss of soil particles from behind the wall, and lowering ground water level in neighborhood. Thorough backfilling behind this type of wall is also very difficult.

(2) Sheet pile wall

Due to difficulties in driving sheet pile through firm stratum, this type is rarely used in urban area, where the soil stratum above weathered zone of bed rock is rather thin.

Some exception are in those areas near river or harbor where fluvial or marine deposits are relatively thick. The high price of sheet pile in Korea is another major factor which discourages its use.

(3) Soil-cement column wall

Soil-cement columns are installed consecutively prior to start of excavation to form a retaining wall. They are made either by drilling and mixing soil by auger with cement or jetting cement milk with very high pressure into soil, thus churning and mixing soil with cement. The former method is quicker and less expensive then the latter. Therefore the number of construction case by the former method are increasing. But both method could not be adopted in boulder or weathered rock zones. The small compressive strength of soil-cement is also a disadvantage of this type wall. Therefore reinforcing members are usually inserted within columns. (Fig.1)

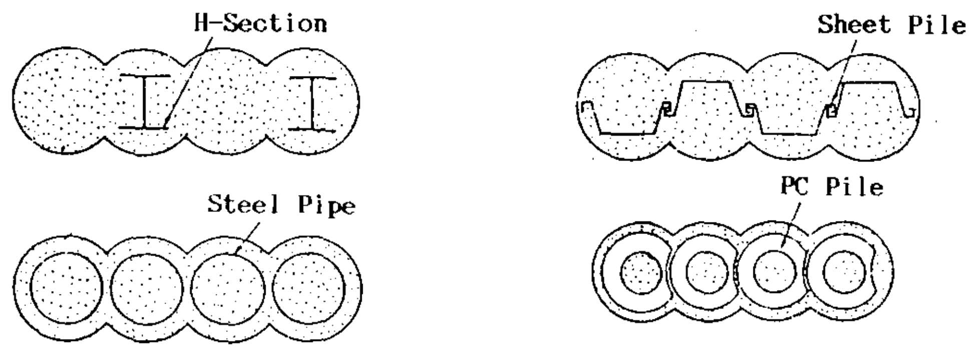

Fig.1 Reinforcing members in soil-cement columns

(4) Prepacked concrete column wall

About 40cm diameter hole is drilled first and then prepacked concrete is cast to make column like cast-in place concrete pile. Another precast concrete column is installed next to it to form a wall.

The depth of this type of wall is not limited by ground condition. Fabricated reinforced steel or H-section is inserted in the concrete column. The high compressive strength of prepacked concrete is very effective in resisting bending moments. Therefore this type of wall is very efficient in retaining earth pressure.

But the position and verticalness of drill holes for columns should be precise to eliminate apertures between columns and to form a clean wall. But in most of cases they are almost impossible and additional grouting between and behind columns have been necessary.

(5) Slurry Wall

Ractangular shape trench is excavated by special drilling rig and, then it is stabilized by bentonite slurry until concrete is poured in through tremie pipe to form a reinforced concrete wall.

The thickness of this type of wall is relatively larger(80cm-120cm) and more rigid than any other type of wall. Most of times, this type of wall is used as permanent basement wall of building as well as temporary retaining structure.

To construct this type of wall special equipments are necessary and the costs are high. But the rigidity and integrity of wall reduces the chances of damaging adjacent structure during excavation. Considering additional cost for basement wall in other wall systems and appeals from the neighborhood, the slurry wall is not, depending on situations, always expensive.

Support system

The above wall systems are supported mainly by two type of support systems during excavation.

(1) Strut system

Usually strut are installed between two opposite retaining walls. H-sections are most common type of member for strut. Chanel sections are also used occasionally.

(2) Anchor system

When retaining structures are supported by steel wire or strands anchored in the ground at some distance behind the wall, there are plenty of room available for construction work of subsurface structure of a building. Therefore most contractors prefer anchor system to strut system if situation allows. But Korean property law requires the contractor to get permission to install such anchors from the owner of neighboring properties.

REVIEW ON DESIGN METHODS

Appled earth pressure

Retaining structure should resist the earth pressures acting on them. Several type of earth pressures have been proposed upto now. Among them two type of earth pressures are most widely applied currently.

(1) Triangular distribution

Earth pressure is increased with depth for rigid wall, resulting triangular distribution. Even though the earth pressure on the middle portion of a flexible wall like sheet pile reduces from hydrostatic value, a triangular distribution is applied on most of the reinforced concrete retaining structures.

Active earth pressure is used in designing of retaining structure while earth pressure at rest is used for basement wall. This shape of earth pressure distribution is not appropriate for flexible walls.

(2) Quadrilateral distribution

If natural ground is exposed without any support during excavation, the soil is loosened and earth pressure is decreased. In soldier pile and wood lagging system the earth pressure at the lower portion of the wall becomes smaller and upper protin lager than the hydrostatic earth pressure.

In this case rectangular or trapezoidal shape of earth pressure distribution is more reasonable. Some of such earth pressure have been proposed. (Fig.2)

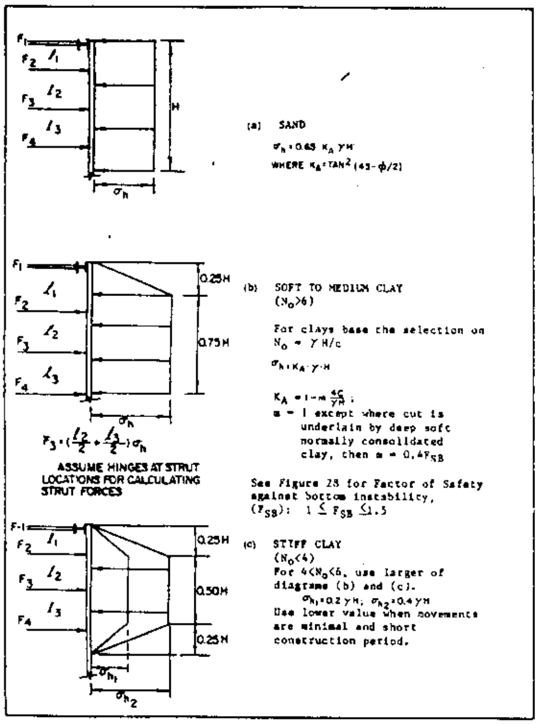

Fig.2a Pressure distribution for braced flexible wall

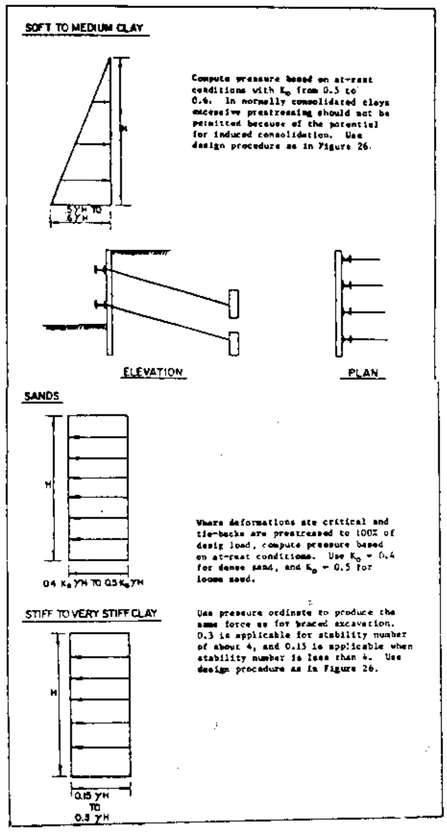

Fig.2b Pressure distribution for anchored walls

Analysis method

There are several methods of analysis for retaining structures. The design of support system is rather simple since the supporting member are designed according to the reaction obtained during analysis of wall structures. The analysis methods currently used are as follows.

(1) Simple beam analysis

When wall is flexible, it could be approximated conservatively as simple beams between supports.(Fig.3a) This method is the simplest but sometimes an uneconomical design results. The wall movement could not be calculated by this method.

(2) Continuous beam analysis

The wall would better be treated as continuous beam rigidly supported at anchors or struts. The bending moments and shear forces calculated by this method are more accurate than the above method. But the wall movement could not be predicted.

(3) Beam on elastic foundation analysis

Wall is treated as a continuous beam acted upon by earth pressure and elastically support by wales and ground in front of wall.(Fig.3b) In this method the wall movement is calculated. But it should be emphasized that the predicted wall movements are not so reliable values because the input data for modulus of subgrade reaction of ground are only experimental values. No reasonable procedures to obtain such modulus subgrade reaction of soil in front of retaining structure are established yet. Some values which are currently used in analysis are given on Table 1. In this method of analysis the ground movements behind the wall is out of considertion.

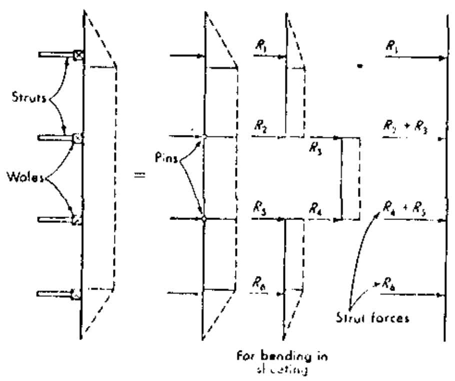

Fig.3a Simple beam analysis

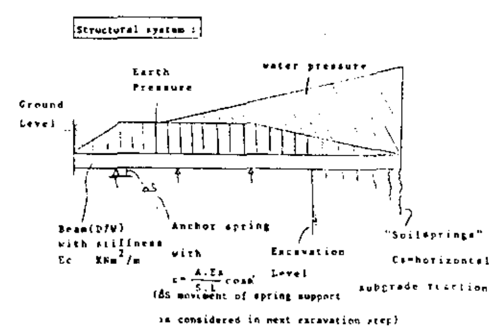

Fig.3b Beam on elastic foundation

Table 1 Some moduli of subgrade reaction currently used

Company	Used values
A	Bowels's method: kh=12(cNc+0.5BNr+q'Nq)
B	Terzaghi's estimation
C	Sand or gravel: Kh=3000 t/m3,Rock:Kh=10000 t/m3
D	Applied earth pressures are varied according to wall displacements between pa and pp

(4) Soil- structure interaction analysis

Retaining wall, support systems and ground behind and in front of wall are incoporated in a F.E.M. mesh. An example is shown on Fig.4. Excavation stages are closely simulated. Therefore all informations on stresses and displacements of structures and ground behind and in front of wall are calculated.

Since deformation modulus of ground is used instead of modulus of subgrade reaction in analysis, more reliable input data are possible. If reasonable input data are available, this is so far the best method.

Comments on analysis methods

Since the structural safety of retaining structure during excavation work is a must and not much a problem nowadays, people are more concerned about the damages inflicted on the adjacent structures. In this respect, the F.E.M. analysis with retaining structure and ground in its mesh might be the best solution. In this analysis the soil-structure interactions between retaining wall and ground are automatically considered.

If a beam on elastic foundation analysis method is adopted, the value for modulus of subgrade reaction of ground should be justified, and the prestressing forces should be duely incorporated in excavation simulation for calculation of wall displacement.

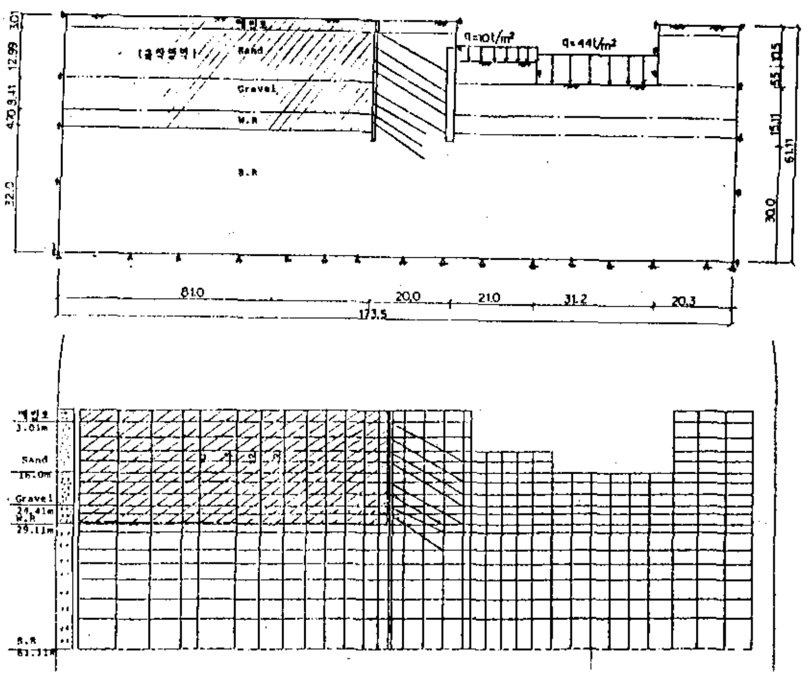

Fig.4 F.E.M. mesh for analysis of excavation work

SOME MISTAKES IN CONSTRUCTION OF RETAINING STRUCTURES

Quite a few of critical mistakes in construction of temporary retaining structures are made nowadays due mainly to forman's ignorance of structural concept and construction engineer's lack of knowledge of design philosophy for the structures. These mistakes could be eliminated if capable superviors are employed. But situations are such that owners of the structures are reluctant to pay supervisory fee in addtion to design fee. The following are some examples which are frequently encountered at construction sites.

Wall System

Often maintaining verticalness during installation of soldier piles or cast-in-place concrete colums is a problem. If they are offset from verticalness, the resulting walls became undulated and untight. Groundwater verticalness, the resulting walls became undulated and untight. Groundwater inflows through apertures between concrete columns could wash out soil particles from behind the wall resulting in damages on adjacent structures.

Uneven alignment of soldier pile or concrete columns leave spaces between wall and wales, and then wales are acted upon not by evenly distributed loads but by irregular concentrated loads. Also the spaces between soil-cement or prepacked concrete columns and wale could load to unstable wall.

Safety of wale

Wales act as continuous beams supported by struts or anchors. The steel sections for beams are designed to resist bending moments and shear forces, and the points, where concentrated forces such as reaction forces are acting, should be stiffened. But at construction site it is easier to find unstiffened wales at strut or anchor points than stiffened ones.

When a single H-section is used as a wale, each strand is set separately on flange. In this type of wales holes for strands to pass are cut in flanges leaving reduced flang areas. Often designers neglect the reduced flange areas when they check for resistance to bending moments. Another neglected fact is that the flanges should be supported by stiffeners.

In this case the number strand would better be even because different number of strands at opposite side of web of a H-section results in unbalanced forces and twisting torque in the wale.

Problems with strut

Since struts are designed to support compressive forces, the most important factor in construction stages is to maintain required design slenderness ratio. But engineers at site often believe that bracing system between struts without any rigid supports at some points provide lateral supports to struts and reduce slenderness ratio to design value. Shown on Fig.5 is a design plan of strut system which failed when the excavation had reached to a depth of 28 m.

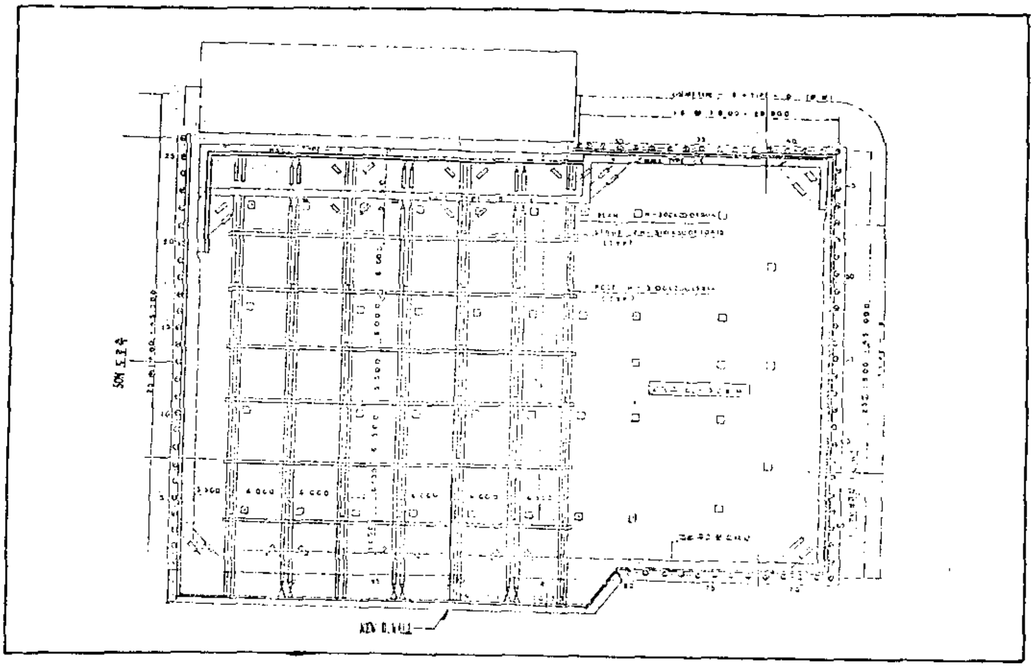

Fig.5 An example of strut system with long unsupported length

If struts are long, the changes in length due to temperature changes and the shortening due to compressive forces are not negligible. Suppose that the length of a strut is 50 m, then the seasonal variance of length could be 1cm and the amount of shortening as much as 2 cm if average compressive stress developed due to earth pressure is 1 kg/cm2. This amount of wall displacement could affect adjacent ground and structures.

Earth anchors

Each part of earth anchor, such as cone, free length, packer and bonded length, should function exactly as they are meant to make a good earth anchor. But in many cases, strands are not set properly in cone and slippage occurs. Therefore the prestressing is not introduced as designed and larger wall movements than calculated result. By author's experiences the mesured loads on anchors right after introduction of prestressing were about 50%-60% of expected values.

The main role of packer is to seperate the free and bonded lengths of an earth anchor. Therefore the packer should remain inflated during pressure grouting the bonded length. But it is not rare to find at construction site that the grout hole for packer is left open while the bonded length is being pressure grouted. In these cases, the grout milk for the bonded length spills up passing the packer portion and cover the free length of anchor. Then the quality of an anchor could not be confirmed and the prestressing the anchor is impossible.

In some construction sites, poor workmanship results in bent strands. When they are bent, prestressing in an anchor could not be correctly introduced.

INSTRUMENTATION

Collection of data

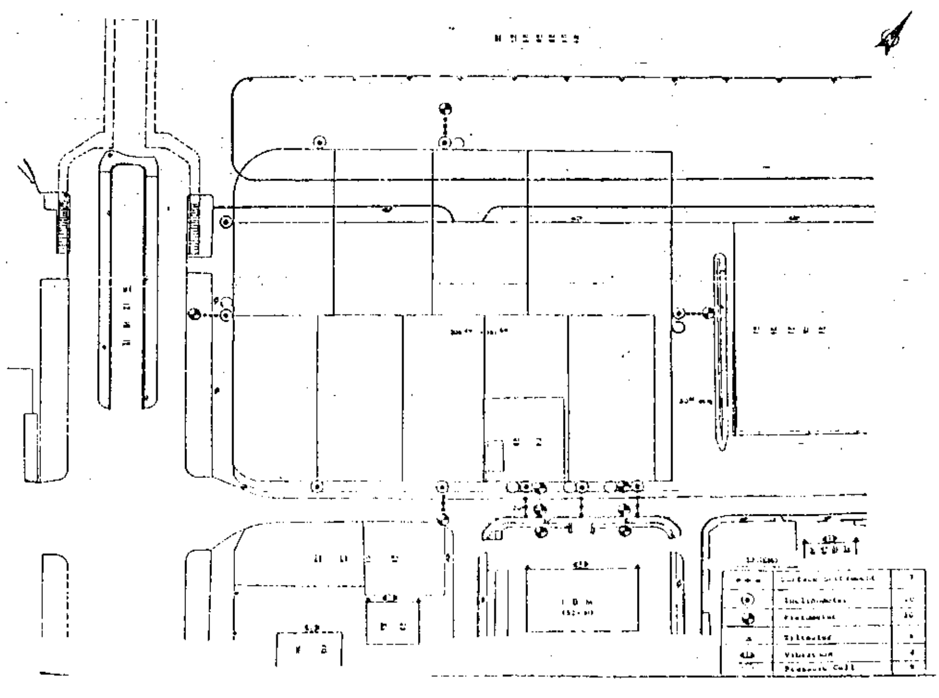

Fig.6 Instrumentation plan

To monitor the behavior of retaining structure, neighboring ground and adjacent structures during excavation work, instrumantation is necessary to collect data for displacements of wall, stress developed in structural members, horizontal and vertical ground movements, settlements and tilting of adjacent structures, loads acting on anchors, earth pressure acting on back of wall and level of groundwater. Fig.6 shows an example of instrumantation plan.

Most of times all of these data are collected during urban excavation work for big buildings or structures, but sometimes only parts of them are enough for control of excavation work. Since the cost of instruments are rather high, engineers should be careful about their number and location to be installed.

Evalution of collected data

The collected data are used to evaluate safety of the retaining structures and integrity of excavation work and to predict future behavior of structures and ground. As a result, modification in design is made if necessary. Therefore the evaluation should be made by capable and experienced engineers who are familiar with shortcomings of current design methods and construction practices.

One of the important steps toward good instrumentation and evalution of data in Korea nowadays is to persuade the owner of new structures that the high cost of instrumentation and hiring capable supervisor pays off well.

CONCLUSIONS

There still are quite a few things which should be improved in designing temporary retaining structures. Most of all preparing input data especially for ground properties is the most important. Choosing right method of analysis and performing realistic simmulations should also be given due considerations.

Since the quality of construction work of small contractors are still unsatisfactory, close supervisions are mandatory for very important projects. The collected data by good instrumentation might be the only reliable informations for behaviors of structures and ground during excavation.

Therefore it is advisable for all who may concern with the excavation to convince the owner of new structure to willingly pay for instrumentation and supervision of the excavation work.

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